Scattering from the Sea Surface and Bubbles, and the ASIAEX East China Sea Experiment

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LONG-TERM GOALS

To achieve a comprehensive understanding of the physics of mid- to high-frequency scattering from the air-sea interface, as it is determined by the sea surface wave spectrum, near-surface bubbly media and ocean dynamics. To develop physics-based, predictive sonar models for scattering and propagation phenomena.

OBJECTIVES

A focused objective is to elucidate the detailed physics of scattering from bubbles in very close proximity to an air-water interface. A more broader objective is to better understand the strength and coherence of forward scattering from the sea surface, including excess attenuation caused by bubbles in the proximity of the sea surface, the frequency dependence of scattering and transition from coherent to incoherent properties, and the impact of sea surface forward scattering on SAS processing schemes.

APPROACH

The approach for the bubble studies utilized the laboratory setting in order to achieve precise control of conditions for scattering measurements from bubbles. A key person engaged in these laboratory studies has been George Kapodistrias, who completed his Ph.D. studies in February.

The approach for the broader objective concerning sea surface scattering involved field studies with focus primarily on forward scattering from the sea surface. Most needed was data spanning both a large range in frequency and environmental conditions, in order to test existing models and guide efforts towards modeling improvements. The ASIAEX (Asian Seas International Experiment) experiment conducted in the East China Sea in June 2001, met this need.

Our approach in both cases includes a parallel modeling effort as part of the data interpretation. For the laboratory work we have developed a model based on a multiple scattering series and ray-synthesis [1]; and for the field work on scattering, models are used that have the small slope approximation at their core [2].

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14. ABSTRACT
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WORK COMPLETED

This year data analysis from two laboratory experiments on bubbles was completed, one involving monostatic and bistatic scattering from a bubble located near a flat air-water interface [1], and a follow-up experiment involving monostatic scattering from a bubble located near a roughened air-water interface [3].

In terms of field work, the ASIAEX East China Sea experiment was successfully carried out 29 May - 9 June from aboard the research vessel *Melville* [4].

RESULTS

The first major task completed was analysis of laboratory measurements of scattering from a bubble located near a flat and roughened air-water interface. Figure 1 is photograph of a bubble suspended below a roughened air-water interface (using a fine thread), and illustrates the controlled nature of these measurements. It was found that the rms waveheight σ combined with grazing angle θ and frequency, establish a critical parameter, $\chi = 2\, k\, \sigma \sin(\theta)$, where k is acoustic wavenumber, that governs the behavior of the field backscattered from a bubble located beneath a roughened air-water interface. This, of course, is the well known Rayleigh parameter from the study of scattering from rough surfaces; here it determines the coherence among the four paths that contribute to bubble scattering. The range over which χ has influence in this process is $0 < \chi < \pi$; for $\chi > \pi$ there is no change in the scattering versus depth behavior for increasing roughness. Figure 2 shows results comparing our theoretical model curves and measured data for the case of $\chi = 0$ (flat surface) and $\chi = 0.3$ (slightly roughened surface).

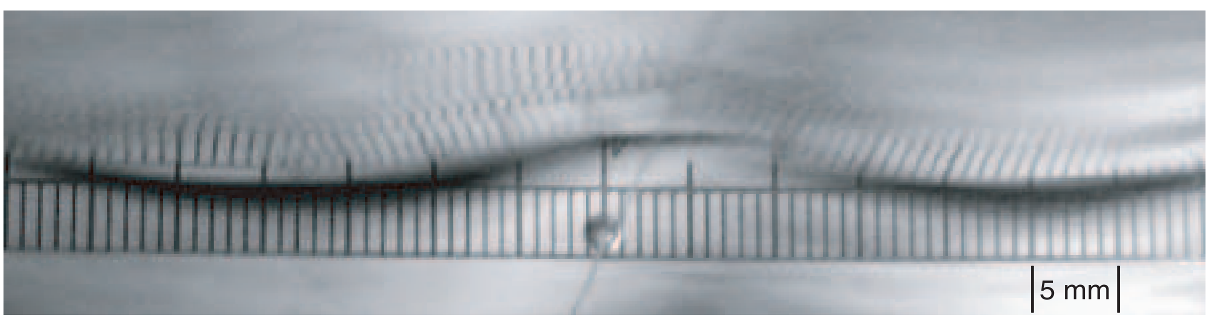

Figure 1. Photograph of a single bubble below a slightly roughened air-water interface and scaled ruler (1 mm graduation).[Figure is for demonstration purposes only, and illustrates how the rough surface was quantified using digital photography. Acoustic measurements were not made while the scaled ruler was in the water.]

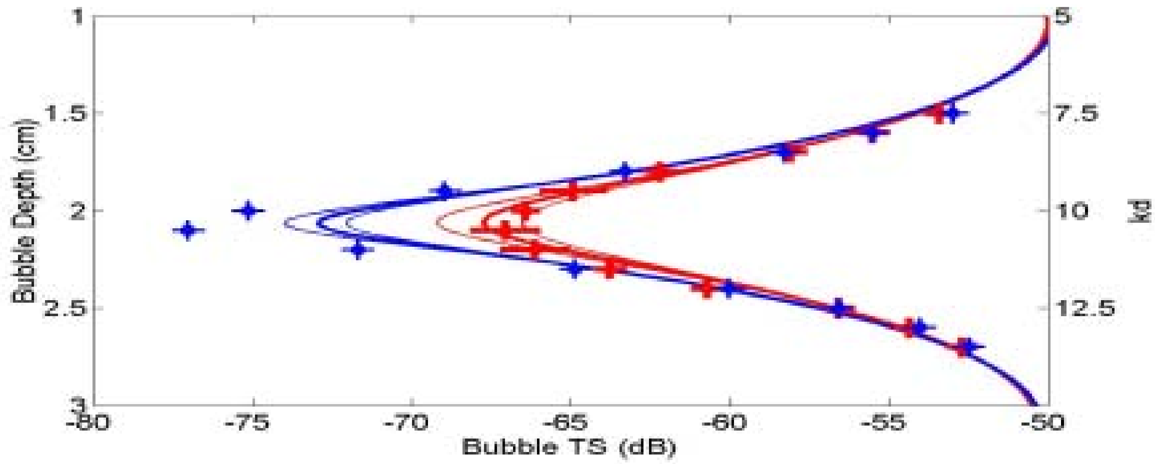

Figure 2. Theoretical curves for scattering from a single bubble located close to a flat (blue lines) and wind-roughened (red lines) air-water interface. The flat surface is characterized by roughness parameter $\chi = 0$, and the roughened surface is characterized by $\chi = 0.3$. Data points from corresponding flat and rough surface experiments are shown with same color code. [Depth of the 1200 micron bubble is shown on the left-hand scale in cm, and on the right-hand scale in terms of kd, where k is acoustic wavenumber based on frequency of 120 kHz. Three model curves are shown for each case, which are based on the high, low and average background level (which influences the model results). The thickest line in each case is based on the average background level.]

The second major task completed was ASIAEX East China Sea experiment, carried out from 29 May to 9 June from aboard the research vessel *Melville*. Figure 3 shows the experimental site in the East China Sea.

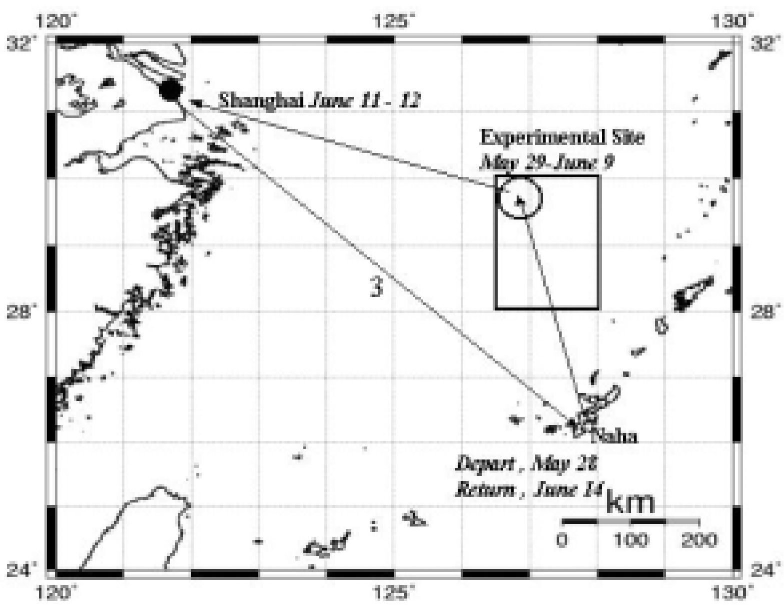

Figure. 3 Cruise course for the R/V Melville for the ASIAEX experiment in the East China Sea.. The majority of time at the experimental site was spent near the center of the 30 km-radius circle shown. The rectangle delineates the research area approved by the State Oceanic Administration of the P.R. China.

Science teams from APL-UW, MPL-SIO, and URI deployed a constellation of instruments from the R/V *Melville* to measure acoustic propagation and scattering over a broad frequency range (2-20 kHz), along with environmental measurements (sound speed, sea surface directional wave spectra, and seabed parameters) required to interpret results. The cruise report [4] provides a summary of the experiment and includes some preliminary results.

Presented here is an example of one kinds of measurements that pertain to shallow water propagation and surface forward scattering. These measurements were made using an acoustic source known as BASS (Broad band Acoustic Source System) that provided capability of transmitting pulses over the frequency range of 2 kHz to 20 kHz. The BASS system was deployed off the stern of the *Melville* and the source depth was variable. Signals from BASS were received on MORAY (Moored Receiving Array), an autonomous moored vertical line array, consisting of two, 4-element vertical line arrays. For the East China Sea deployment, the upper array was place at depth 26 m, and the lower array was placed at depth 52 m. Typical propagation conditions in the East China Sea are illustrated by the ray diagram (Fig. 4), and the signals received by MORAY that correspond to the eigenrays in Fig. 4 are shown in Fig. 5.

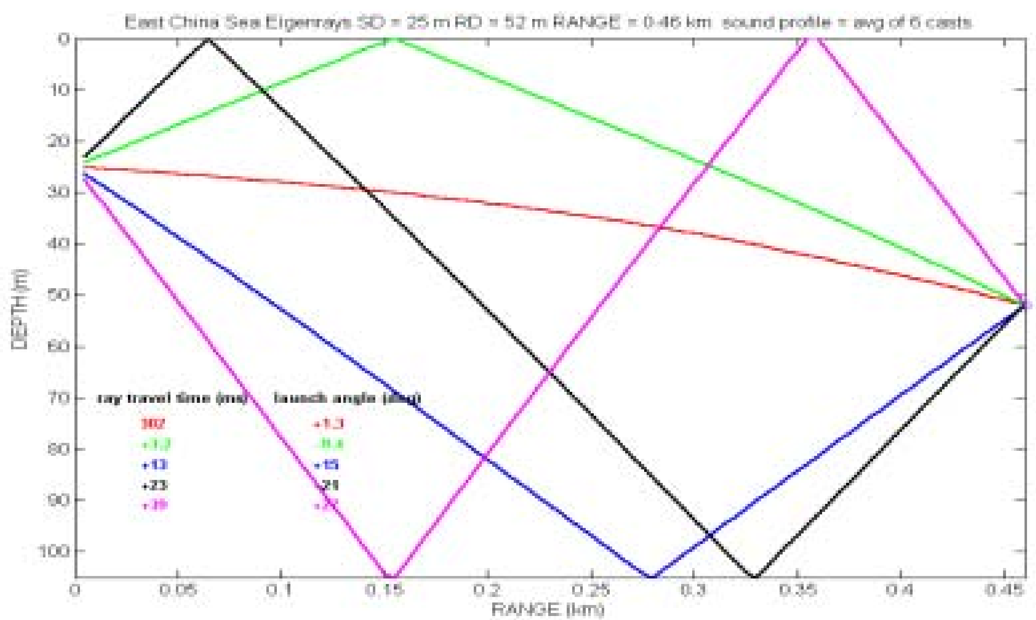

Figure 4. Plot of the first 5 eigenrays for an acoustic source at depth 25 m, receiver at depth 52 m and range 460 m, corresponding to one of the geometries used for East China Sea shallow water propagation and forward scattering measurements.

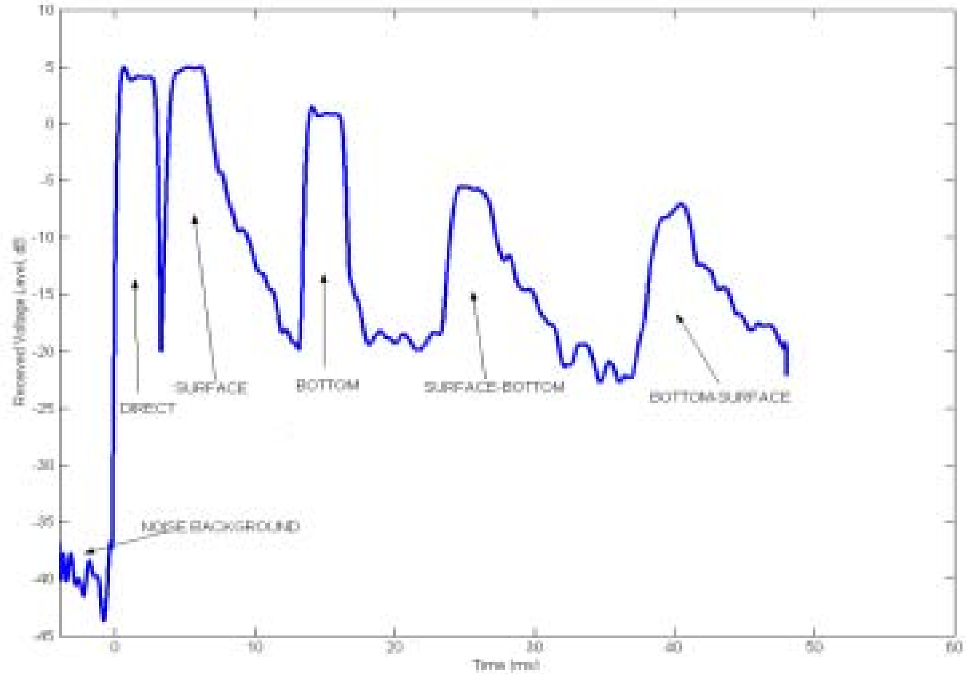

Figure 5. Ensemble-averaged squared voltage (proportional to intensity) of signal transmitted from BASS (2 ms cw, frequency 16 kHz) and received on the MORAY at depth 52 m. The primary arrivals are shown: direct path, surface bounce path, bottom bounce path, surface-bottom path, and bottom-surface path. These correspond to the five eigenrays shown in Fig. 4.

Measurements such as those shown in Fig. 5 were made during two continuous measurement periods, each exceeding 24 h. The 24 h period was selected in order to capture environmental effects in the data. The frequency range for these measurements spanned the nominal range of 2-20 kHz, and thus the goal of spanning both a large frequency and environmental range was achieved. In brief, the ASIAEX East China Sea 2001 experiment produced a valuable set of measurements on acoustic propagation and scattering in an Asian littoral sea, along with the environmental measurements required for its interpretation. These measurements will be analyzed over the next two years by several investigators.

IMPACT/APPLICATIONS

Our laboratory work on scattering from bubbles in well-controlled conditions has direct impact field models. For example, the agreement with our theoretical predictions lends credence to a field model for contribution of near-surface bubbles to the apparent backscattering cross section per unit area of sea surface [5] that embodies the same physics but can otherwise not be verified because field conditions cannot be sufficiently controlled. Furthermore, these studies have clarified the relation between monostatic and bistatic scattering from near surface bubbles in field conditions as discussed in ref.[2].

The new field data base from the ASIAEX East China Sea experiment, which spans both a large range in frequency and range of environmental parameters, will have far reaching impact on several studies concerning shallow water propagation and sea surface scattering. For example, these data will be brought to bear on research towards understanding the performance bounds of long-range Synthetic Aperture Sonar (SAS), for which the sea surface bounce path is key.

TRANSITIONS

This work relates directly to other ONR programs (both 6.1 and 6.2) that involve mid- to high-frequencies, and scattering from the surface and near-surface bubble layer, and contributes to a physics-based foundation for models used in mid to high-frequency sonar, and SAS system performance predictions.

RELATED PROJECTS

Programs that relate to, and complement this work include*: Turbulence, bubble populations and high frequency*, (D. Farmer), and *Fluctuations in High Frequency Acoustic Propagation* (W. Hodgkiss and W. Kuperman), *Environmental Limitations of Active Synthetic Aperture Sonar Processing* (Enson Chang).

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